Coal Technologies incorporating CO_2 Capture – A Program for Research,Development, Demonstration and Deployment

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Options for CO_2 Response

- Conservation (Yes - but what about the rest of the world?)
- Renewables (Yes - but not enough as a percent of generation)
- Nuclear (Ultimately Yes – but questions on waste disposal)
- Adaptation (Probably Yes – we usually do)
- Switch from Coal to Natural Gas (Maybe but not enough cheap Natural Gas)
- CO_2 Capture and Sequestration –CCS (Maybe but site specific and costly)

Notes :

US Coal Power Plants emit > 2 billion metric tons of CO_2/yr (~31% of US and 8% of World CO_2 emissions).

1 billion metric tons/yr = ~25 million bpd of supercritical CO_2

Economic Evaluations of SOA Coal Technologies with CO_2 Capture and Sequestration (CCS)

At current State-of-the Art (SOA) there is no “Silver Bullet” technology for CCS. Technology selection depends on the location, coal and application

- Sequestration is the key technical issue. Probably location and geology dependent
- CO_2 capture adds considerably to Cost of Electricity(COE)
- IGCC/Shift carbon capture least cost for bituminous coals
- IGCC/Shift and PC plants with amine scrubbing are very similar cost for high moisture sub-bituminous Coals
- PC with amine scrubbing least cost for Lignites
- CFBC can handle high ash coals and other low value fuels
- Oxyfuel (O_2/CO_2 Combustion), Chemical Looping are technologies at developmental stage

EPRI Economic Estimates for 500 MW Clean Coal Technology Plants without CO_2 Capture - 2003. Bituminous Coal

Fuel	Pittsburgh #8 Coal	Pittsburgh #8 Coal	Natural Gas	Natural Gas
Technology	Ultra Supercritical PC	IGCC E-Gas No Spare/ With Spare	NGCC	NGCC
Capacity Factor	80	80	80/65/40	80
Fuel Cost $/MBtu HHV	1.5	1.5	3.5	4.9
TPC $/kW	1286	1210/1305	440	440
COE $/MWh	46.5	46/48	36.5/40/47.5	46.5

EPRI Economic Estimates for IGCC & PC Plants without CO_2 Capture – 500 MW with Low Rank Coals

Technology	IGCC E Gas	IGCC Shell No Spare/ Spare	PC Sub-critical	IGCC E Gas	PC Sub-critical
Coal	Wyo. PRB	Wyo. PRB	Wyo. PRB	Lignite	Lignite
TPC $/kW	1640	1480/1690	1330	1830	1340
Coal Cost $/MBtu HHV	1.0	1.0	1.0	0.5	0.5
COE $/MWh at 80% Capacity Factor	54	48/54	44	55	43

IGCC for Low Rank Coals - Improvements Needed

- Although entrained flow gasifiers can process all ranks of coal the *existing commercial gasifiers all show a marked increase in cost and reduced performance with low rank and high ash coals*.
- For slurry fed gasifiers (Texaco, E-Gas) the *energy density* of slurries with high moisture and/or high ash coal *is markedly reduced* which increases the oxygen consumption and reduces the gasification efficiency
- For dry coal fed gasifiers (Shell) there is an *energy penalty* (and therefore reduced steam turbine output) *for drying* the high moisture coals to the low moisture content necessary for reliable feeding via lock hoppers and pneumatic conveying
- *Although IGCC is closely competitive with PC for bituminous coals the PC capital costs are 300$-400 $/kW lower than IGCC for low rank coals and the PC COE is ~20% lower than IGCC*
- Potential improvements include slurry preheating & flashing, Coal/CO_2 slurry, coal pump (e.g.Stamet) or other device to deliver as received coal reliably at pressure, Transport gasifier etc

Economics of IGCC and USC PC with CO_2 Capture. (Gasification Technologies are not all alike!)

Nominal 450 MW net Plants Pittsburgh #8 Bituminous Coal, All IGCC with spare gasifiers

Technology	IGCC Texaco Quench	IGCC Texaco Radiant SGC	IGCC E-Gas	IGCC Shell	PC Ultra Supercritical
MW no capture	512	546	520	528	600
TPC $/KW no capture	1270	1500	1305	1620	1235
COE $/MWh no capture at 80% CF	48.5	53.5	48	55.5	45
MW with capture	452	486	442	465	460
TPC $/kW with capture	1620	1900	1870	2190	2110
COE $/MWh with capture	61	67	67	73.5	75.5
Avoided Cost of CO_2 $/mt	18	21	29	29	42

Canadian Clean Power Coalition (CCPC) Study for Low Rank Coals with CO_2 Capture

(as reported by CCPC- except PC Subbituminous EPRI interpolation)

Coal	Alberta Sub bituminous	Alberta Sub bituminous	Saskatch. Lignite	Saskatch. Lignite	Saskatch. Lignite
Technology	USC PC Amine Scrubbing	Texaco quench IGCC	USC PC Amine Scrubbing	Shell IGCC	Oxyfuel O_2/CO_2 Combust'n
Net MW	316	437	311	361	373
Coal Cost US $/MBtu	0.48	0.48	0.85	0.85	0.85
TPC US $/kW	2585	2205	2826	2847	3960
COE US$/MWh at 90% CF	64	61	74	82	97

IGCC with CO_2 Capture for Sub-bituminous Coals and Lignite - Comments

- Although detailed CO_2 capture studies have not yet been completed, the reduced performance of slurry fed gasifiers (Texaco and E Gas) with high moisture low rank coals will make IGCC less competitive with PC for these coals than was found to be the case for bituminous coals
- In the Canadian CPC study Fluor made several process improvements that reduced the steam consumption for their Econamine (MEA) process (used for post combustion CO_2 removal in PC plants) from 1750 to 1185 Btu/lb of CO_2 .

  For Saskatchewan lignite the Shell IGCC COE was greater than for PC with capture (Texaco declined to bid). For the Alberta sub-bituminous coal (similar to PRB) the Texaco IGCC and PC COE's were very similar.

The Power Industry needs Technology Options for Responding to Potential CO_2 Legislation

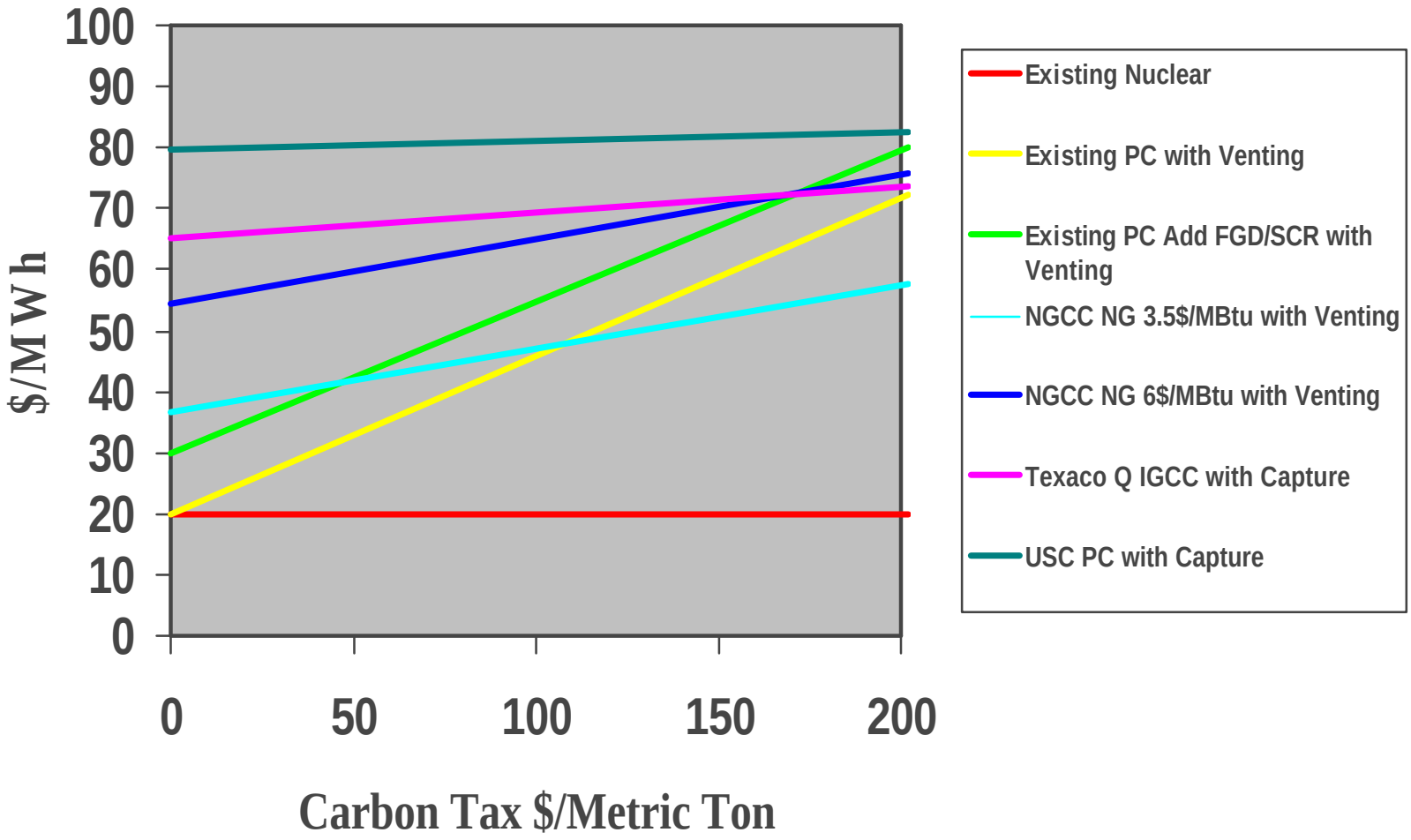
1. Ultra Supercritical (USC) PC and CFBC

- PC designs based on advanced USC materials increase plant efficiency and reduce the cost of capture from flue gas
- Improvements and innovations for CO_2 capture from flue gas need to be investigated and developed
- USC materials can be applied to CFBC thereby extending the range of usable fuels to poorer quality coals, petroleum coke, biomass and wastes.
- CFBC now being offered at 400-600 MW Supercritical.
- Any improvements to CO_2 capture from flue gas could also be applied to CFBC.
- Innovative Combustion technologies such as Oxyfuel, Chemical Looping and Pressurized PC are at an early stage of development but may find application

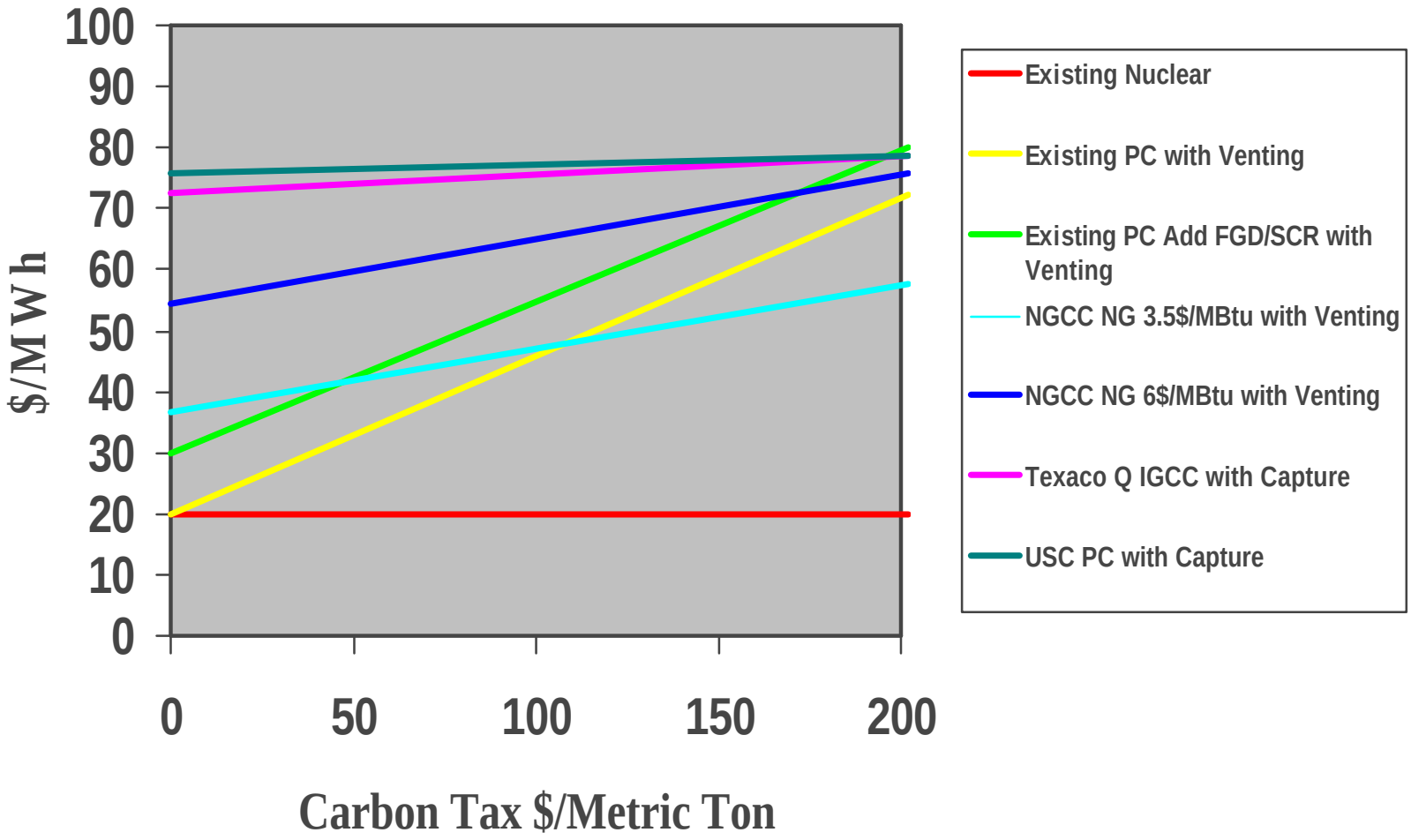
The Power Industry needs Technology Options for Responding to Potential CO_2 Legislation 2. IGCC

- To become an Option IGCC needs Deployment Incentives
- Uniquely among the coal technologies IGCC can also find application in co-production of transportation fuels and Hydrogen
- IGCC's advantage over PC for bituminous coals also depends on the specific gasification technology.
- For CO_2 Capture a comprehensive RD&D program for improved performance at high pressure (HP) and with low rank sub-bituminous and lignite coals is needed
- For Hydrogen production and maximum CO_2 capture high pressure single stage entrained quench gasifiers preferred.
- Gasifiers that produce some CH_4 have higher gasifier efficiency and lower O_2 consumption but reduce the achievable CO_2 capture via the Shift. However if 75% CO_2 capture is acceptable then HP two stage entrained or fluid bed gasifiers may be more efficient and economic

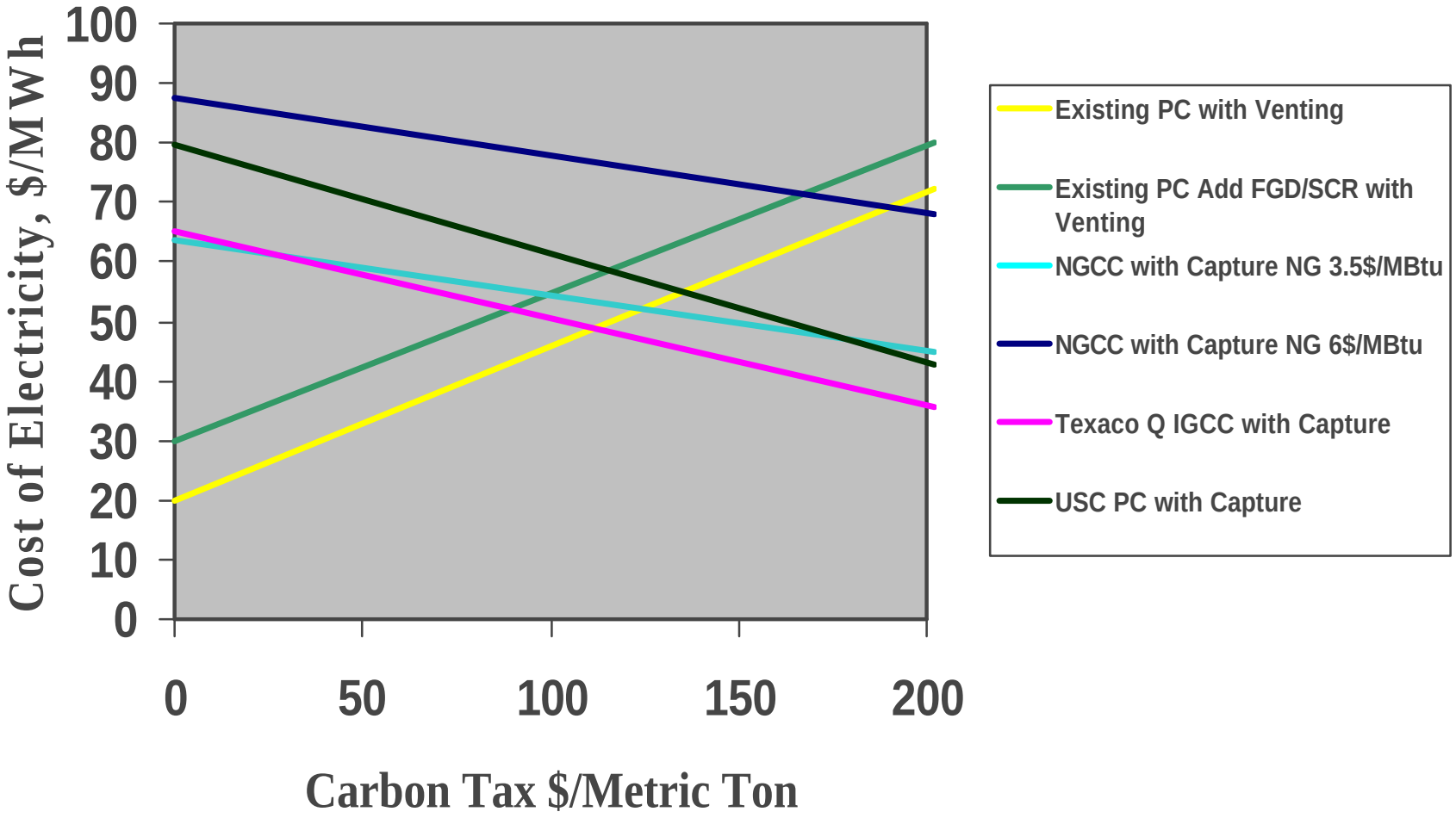
Effect of Carbon Tax on Cost of Electricity for Various Technologies – Bituminous Coal



Effect of Carbon Tax on Cost of Electricity for Various Technologies – PRB Coal



Combined Effect of Carbon Tax on Emissions & Capture Credit on Cost of Electricity for Various Technologies - Bituminous Coal



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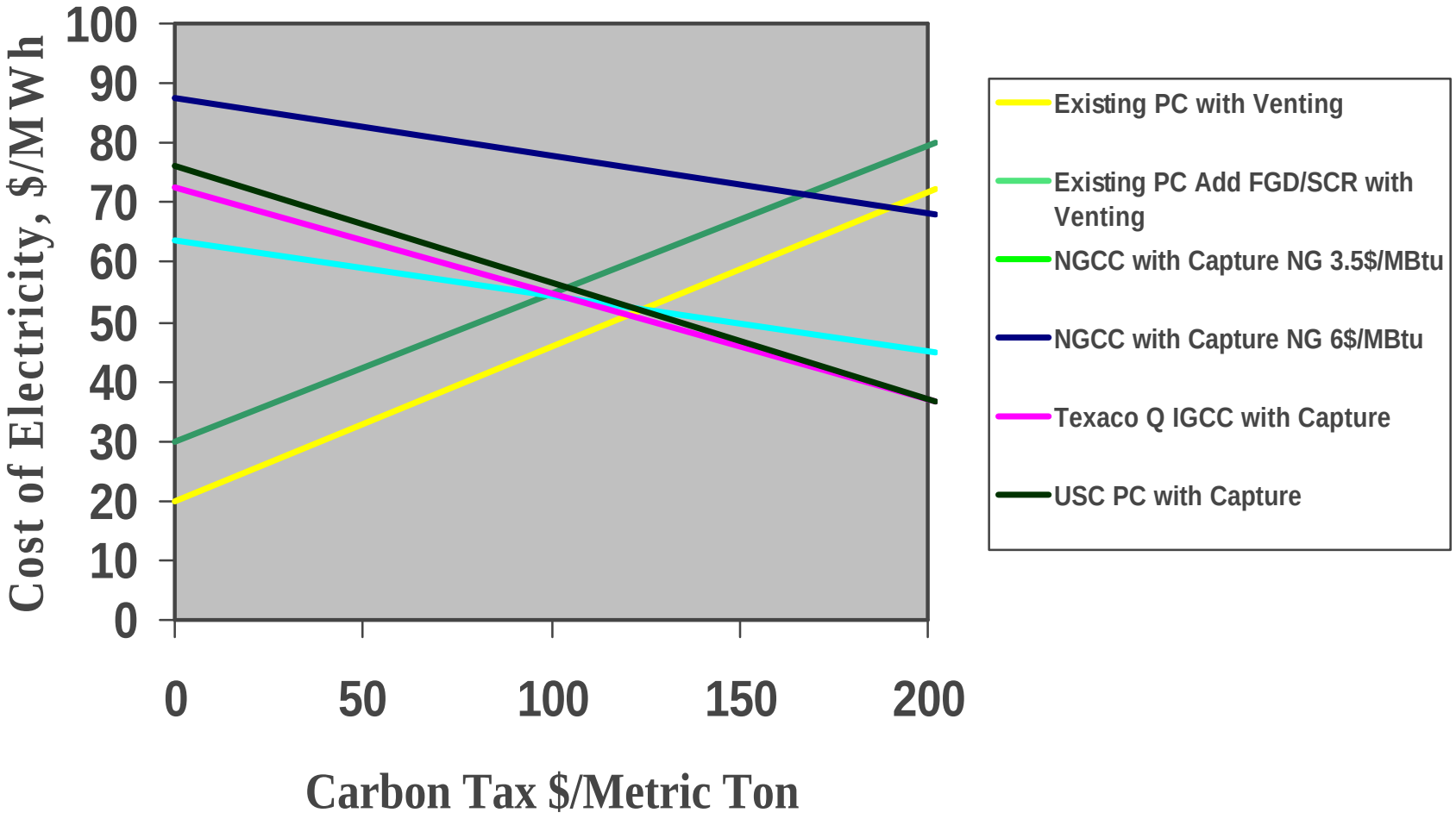

Effect of Carbon Taxes on Fuel and Technology Selection

- Main issue is with the existing power plants. U.S. has 320 GW of coal power plants but only ~100GW have FGD.
- The paid off capital on most US coal plants is a great economic advantage.Only at a Carbon tax of tax ~200$/mt is their COE up to that of a new IGCC with capture and sequestration. They will probably be kept going as long as possible even if they have to add FGD and SCR and Hg removal. If additional capital of 500$/kW on existing coal plants is required to meet “Clear Skies” the crossover for new coal with capture is still over 150$/mt of C.
- With NG @ 6$/MBtu new NGCC with CO_2 venting is lower COE than new IGCC with CCS until the C tax is ~170$/mt.
- If the purpose of a C tax is to reduce CO_2 emissions and the proceeds were used as credit for technologies with CO_2 capture then capture and sequestration technologies (particularly IGCC) would compete more readily (at lower C tax 70-100$/mt) with existing coal

Future Coal Generation and CCS – Some Issues and Observations

- Does CO_2 Sequestration work? Where ? For how long?
- Can Natural Gas supplant Coal for US Power Generation?
- New Coal Generation will be required under most fuel price scenarios. However CCS costs add~40-50% to COE for IGCC and ~80-90% for PC with bituminous coals.
  Is this going to be acceptable? Can it be significantly reduced?
- The paid off capital on most US coal plants is a great economic advantage. Even with adding FGD,SCR and Hg removal and a large C tax their COE would be much less than new coal. They will probably be kept going as long as possible (See EIA AEO 2004).
  Question/Issue - How can CO_2 emissions be reduced from existing power plants?
- Significant (>50%) CO_2 reductions at new and existing coal plants can only be achieved with CCS.
  Question/Issue - Could Carbon tax proceeds be used to support the costs of CCS?

Coal Technologies for CO_2 Capture and Sequestration (CCS) – Needs

- US CO_2 Policy uncertain. Several legislative proposals. Continued **evaluation and analysis of alternatives** needed.
- Need **Techno-Economic information on Technology Options (buy coal and region**) to inform the policy formulation
- Preferred technology depends on the coal, location and application.
- A **comprehensive R&D,Demonstration and Deployment program** is required to reduce CCS costs for all coal technologies
  - IGCC Deployment Incentives, HP design, low rank coal
  - USC materials, post combustion capture (apply to CFBC)
  - Innovative technologies
- Need better standardized and optimized designs
- Need continual update of techno-economic evaluations as new/improved options emerge to ensure best current information is available to inform policy